

Arthropods of a semi-natural grassland in an urban environment: the John F. Kennedy International Airport, New York

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Received: 16 July 2009 / Accepted: 7 January 2010 / Published online: 23 January 2010
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Abstract Semi-natural grassland habitat fragments, such as those found on airports, might be important for arthropod conservation and biodiversity in urban ecosystems. The objectives of this study were to: (1) describe the arthropod communities present within the grasslands on the John F. Kennedy International Airport and (2) assess spatial and temporal variation in those arthropod communities. We collected arthropods using a vacuum sampler during 2003 and using sweep-net collection methods during 2003 and 2004. During 2003, a total of 1,467 arthropods, representing 17 orders and 68 families were found in vacuum samples. A total of 3,784 arthropods, representing 12 orders and 94 families were collected in sweep-net samples during 2003. In 2004, a total of 3,281 arthropods, representing 12 orders and 85 families were collected in sweep-net samples. Hemiptera, Orthoptera, and Diptera were the most abundant taxa, accounting for 47, 18, and 14% of all arthropods captured, respectively. We found evidence of spatial and temporal variation in arthropod abundance, in particular as noted by fluctuations in Orthoptera: Acrididae and Hemiptera: Auchenorrhyncha. Hemipteran family diversity was also influenced by habitat type. Grassland habitats on airfields, although influenced by anthropogenic factors (e.g., mowing), have the potential to provide

abundant and diverse arthropod communities and might serve as a refugium for such species within urban ecosystems.

Keywords John F. Kennedy International Airport · Insects · Grassland · Sweep sample · Vacuum sample · Urban entomology

Introduction

Although urbanization is considered to be one of the primary causes of declines in arthropod populations around the world (Pyle et al. 1981; McIntyre 2000), little information is known about arthropod communities in urban areas (Frankie and Ehler 1978; Clark and Samways 1997; McIntyre 2000). Within highly urbanized areas, arthropods can be found in a variety of semi-natural and man-made habitats, including natural habitat fragments (Panzer et al. 1995; Blair and Launer 1997; Collinge et al. 2003; Dover et al. 2009), parks (Faeth and Kane 1978; Kadlec et al. 2008; Pöyry et al. 2009), residential and commercial lawns (Cockfield and Potter 1984; Rochefort et al. 2006; Joseph and Braman 2009), roadsides and railways (Eversham et al. 1996; Valtonen et al. 2007), golf courses (New 2005; Yasuda and Koike 2006; Yasuda et al. 2008), brownfield sites (Eyre et al. 2003; Kadas 2006), gardens (Gaston et al. 2005; Smith et al. 2006), and green roofs (Kadas 2006; Schrader and Böning 2006). Research examining the structure and composition of arthropod communities within urban habitats might provide insights into the effects of urbanization on arthropods and information needed to preserve or promote biodiversity in urban ecosystems (Zapparoli 1997; McIntyre 2000).

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Grassland habitats (e.g., hayfields, turfgrass areas) in the eastern United States are typically subjected to anthropogenic influences and dominated by introduced cool-season grasses (e.g., *Lolium arundinaceum* (Schreb.) S.J. Darbyshire [tall fescue]), *Phleum pratense* L. [timothy], cool-season forbs and legumes (e.g., *Trifolium* spp. L. [clovers]) and few native plants (Askins 1997; Norment 2002). Remnant semi-natural grasslands, in particular those serving as habitat fragments, are essential to the maintenance of diverse terrestrial arthropod communities within human-dominated (e.g., agriculture, urbanized) landscapes (Panzer et al. 1995; Picker and Samways 1996; Tschardt et al. 2002; Öckinger and Smith 2007). These semi-natural grassland habitats have the potential to support diverse and abundant populations of arthropods yet little is known of their distribution or ecology in northeastern North America (Goldstein 1997).

With increasing urbanization, airports often provide some of the largest areas of semi-natural grassland habitats available to flora and fauna (Caccamise et al. 1996; Mehrhoff 1997; Greller et al. 2000; Norment 2002) within urban and suburban areas. The extensive semi-natural grasslands of the John F. Kennedy International Airport (JFKIA) represent a fundamentally scarce habitat in the metropolitan New York City area and western Long Island (Buckley and McCarthy 1994; USFWS 1997; NYCDEP 2007). The objectives of this study were to: (1) describe the arthropod communities present within the grasslands of the John F. Kennedy International Airport and (2) to assess spatial and temporal variation in those arthropod communities.

Methods

Study area

This study was conducted on airfield grassland areas of the JFKIA (40°38'N, 73°47'W); the airport is located at the southwestern end of Long Island in Jamaica, New York. The JFKIA airfield is 1995 ha in size and in addition to paved surfaces (e.g., aircraft runways and taxiways) is characterized by large areas of cool-season turfgrass, sparse weedy vegetation, and some small trees and shrubs (Barras et al. 2000). The airport is bordered by a protected saltwater bay (Jamaica Bay) to the south and heavily urbanized residential and commercial areas on the other three sides.

The area currently occupied by JFKIA was originally *Spartina alterniflora* L. (smooth cordgrass) marsh (USFWS 1997). The parent material for the soils present on the JFKIA airfield are primarily hydraulic fill and sandy dredge material from the adjacent Jamaica Bay and more recently

construction fill and debris (NYCDEP 2007). Mean annual precipitation at the study area is 1,200 mm per year, with 43% typically falling as rain during growing season (USDA 2005). The average daily temperature during summer is 24°C. The urban soils on the study area consisted of Inwood, Laguardiam and Ebbets series (coarse-loamy or fragmental, mixed, active, mesic Typic Udorthents) loamy fill, sandy dredge, and construction debris mixed with natural soil (USDA 2005).

We identified four grassland habitat areas on the JFKIA airfield that had the potential to be ecologically distinct (Fig. 1): 'Bay runway' (60 ha in size), 'K-extension' (35 ha), 'Between the 4s' (115 ha), and the 'Old meadow' (95 ha) habitat areas. The Bay runway habitat area was grasslands consisting mostly of large amounts (85–90% cover) of *Bromus japonicus* Thunb. ex Murr. (Japanese brome) and *Lespedeza* spp. Michx. (lespedeza; 5–10% cover). The K-extension habitat area was characterized by sparser vegetation, consisting primarily (45–50% cover) of grasses (e.g., *B. japonicus*) with forbs (20–25% cover; e.g., *Solidago sempervirens* L. [seaside goldenrod]) and a few small woody plants (<5% cover; e.g., *Rosa rugosa* Thunb. [wrinkled rose]). The Between the 4s habitat area was predominately cool-season turfgrasses (90–95% cover), such as tall fescue. The Old meadow habitat area was comprised of sparse (<20% cover) native warm-season grasses (e.g., *Andropogon virginicus* L. [broomsedge], *Panicum virgatum* L. [switchgrass], *Schizachyrium scoparium* (Michx.) Nash [little bluestem]) interspersed with trees and shrubs (e.g., *Betula populifolia* Marsh. [gray birch], *Alnus serrulata* (Ait.) Willd. [alder], *Rhus copallinum* L. [shining sumac]). Except for the Old meadow habitat area, which was undisturbed, the grassland habitat areas on the JFKIA airfield were adjacent to runways and

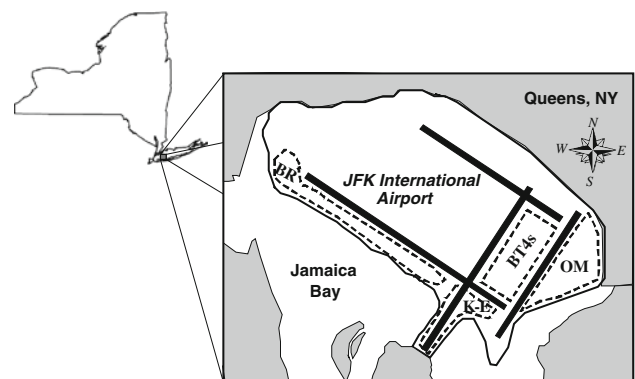


Fig. 1 Location of John F. Kennedy International Airport, Jamaica, NY, and the four habitat areas on the airfield where arthropod samples were collected in 2003 and 2004. BR Bay runway habitat area; K-E K-Extension habitat area; BT4s Between the 4s habitat area; OM Old meadow habitat area

taxiways and mowed to a height of 15 cm twice during the growing season each year.

Vacuum sampling

Arthropod communities in grassland habitats on the JFKIA airfield were sampled using a suction (vacuum) sampling device that was constructed from a Poulan PRO[®] 25 cc leaf-blower (Electrolux Home Products, Augusta, GA). This device was constructed by incorporating design elements from terrestrial arthropod suction sampling equipment described by other researchers (Stewart and Wright 1995; Harper and Guynn 1998). Vacuum samples were collected weekly between 1300 and 1800 h from May to September in 2003 at 30 locations on the JFKIA airfield (Fig. 1). In 2003, samples were collected within the Bay runway ($n = 11$ collection points), the K-extension ($n = 6$), the Between the 4s ($n = 5$), and the Old meadow ($n = 8$) habitat areas (Fig. 1). At each sample collection location, a sample plot was randomly chosen within a 20 m radius of the sample collection point marker. A plastic tub with the bottom removed (providing a sample area of 0.34 m²) was placed onto the ground with the lid in place. The lid was lifted and the vacuum sampler nozzle was inserted into the tub and moved in a methodical manner back and forth over the soil and vegetation for 30 s. The contents of the sample collection net were placed into a plastic freezer bag, placed on ice in the field, and frozen at -20°C within 4 h of collection.

Sweep-net sampling

Sweep-net samples were collected concurrently with vacuum samples (in regard to time and sample collection point) on a weekly basis between 1300 and 1800 h at a total of 30 invertebrate sample collection points (July to September) in 2003 using a standard sweep-net sampling method (Fuhlendorf et al. 2002; Nickel and Hildebrandt 2003; Gardiner and Hill 2006). From a randomly chosen starting point (within 20 m of the sample collection point marker), we walked for ~ 8.3 m, sweeping a 37.6-cm diameter muslin net (Geb-Net Enterprises, Berlin Heights, OH) back and forth in 180° arcs through the vegetation (approximately 5 cm from the ground); each sweep-net sample in 2003 provided an estimated sampling area of 14.1 m². The contents of each sweep-net sample was placed into a plastic freezer bag, placed on ice in the field, and frozen at -20°C within 4 h of collection.

Sweep-net samples were collected weekly between 1300 and 1800 h at a total of 20 collection points (May to September) in 2004. Sweep-net samples were collected at 10, 5, and 5 collection points within the Bay runway, K-extension, Between the 4s habitat areas (Fig. 1), respectively. From a

randomly chosen starting point (within 20 m of the sample collection point marker), we walked for 25 m, sweeping a 37.6-cm wide “D-shaped” muslin net (Geb-Net Enterprises, Berlin Heights, OH) through the vegetation (approximately 5 cm from the ground) and parallel to the direction of travel; each sweep-net sample in 2004 provided an estimated sampling area of 10.3 m². The contents of each sweep-net sample were placed into a plastic freezer bag, placed on ice in the field, and frozen at -20°C within 4 h of collection.

All insect samples were kept frozen and transported to the USDA-APHIS-WS National Wildlife Research Center in Sandusky, Ohio. With the aid of dissecting microscopes, all samples were individually sorted and all arthropods found within each sample were identified to the lowest practical taxonomic level and counted. Arthropod taxonomic nomenclature followed Triplehorn and Johnson (2005). After identification, we classified insect taxonomic families into functional feeding groups based on consensus information primarily from Borror and White (1970), Dillon and Dillon (1972), McAlpine et al. (1981), McAlpine et al. (1987), and Triplehorn and Johnson (2005).

Data analyses

To standardize arthropod capture rates between the two sampling methods and among the four habitats, all arthropod density data (vacuum samples) and relative abundance data (sweep-net samples) were compared using the mean number of arthropods collected per sample. The arthropod density and relative abundance data were not normally distributed and could not be transformed satisfactorily. Therefore, we compared insect abundance among habitat areas using Kruskal–Wallis tests (test statistic H) for each sampling method (and year) and considered differences significant at $P \leq 0.05$ (Zar 1996).

We calculated richness of Coleoptera and Orthoptera families within each of the four habitat types by sampling method/year. Comparison of Hemipteran family diversity was done using rarefied estimates (Gotelli and Entsminger 2001; Magurran 2004) of family richness using EcoSim software (Gotelli and Entsminger 2005). Using within-taxa richness (e.g., familial richness) has been shown to be a viable surrogate for species richness (Magurran 2004).

Results

Arthropod communities

In 2 years of sampling (using two methods), a total of 8,532 arthropods were collected on the JFKIA airfield. Among all arthropods collected during the study, 5 taxonomic classes, 18 orders, and 125 families were represented. In 2003,

1,467 arthropods (1,301 insects and 166 non-insect arthropods), representing 17 taxonomic orders and 68 families were collected and identified in the vacuum samples. Sweep-net samples in 2003 contained 3,784 arthropods (3,732 insects and 52 non-insect arthropods), representing 12 orders and 94 families, whereas 3,281 arthropods (3,197 insects and 84 non-insect arthropods), representing 12 orders and 85 families, were found and identified in the sweep-net samples collected in 2004.

Non-insect arthropods

Although the vast majority (97%) of the arthropods collected at JFKIA were insects (Hexapoda), non-insect arthropods were collected during both the vacuum and sweep-net sampling efforts. Spiders (Arachnida: Araneae) were the most abundant of the non-insect arthropods, comprising 9, 1, and 3% of the arthropods collected during the vacuum sampling, the sweep-net sampling in 2003, and the sweep-net sampling in 2004, respectively. We found mites (Arachnida: Acari) in both vacuum and sweep-net samples, whereas Malacostraca (Isopoda), Chilopoda, and Diplopoda were present exclusively in the vacuum samples.

Insect taxa

Hemiptera, Orthoptera, and Diptera were the most abundant insect taxa, accounting for 47, 18, and 14% of all arthropods captured in the grassland areas of JFKIA. The next most abundant taxa were Hymenoptera (7%), Coleoptera (6%), and Lepidoptera (4%). All remaining taxa accounted for <1% of all arthropods collected during this study.

Hemiptera, including representative families from the Heteroptera, Auchenorrhyncha, and Sternorrhyncha suborders, were the most abundant taxa (a total of 4,035 individuals from 19 families were collected) occurring in both vacuum and sweep-net samples. Auchenorrhyncha and Heteroptera accounted for 29 and 14% of all arthropods collected, respectively. The most frequently occurring Hemipteran families in the vacuum samples were Cicadellidae (leafhoppers) and Miridae (plant bugs). Cicadellidae, Miridae, Delphacidae (plant hoppers), Aphididae (aphids), and Cercopidae (froghoppers) were the most frequently collected Hemipteran families in the sweep-net samples.

Orthopterans were the second most abundant arthropod taxa collected during this study. Acrididae (short-horned grasshoppers) comprised 95% of the Orthoptera collected in the grassland habitats, with representatives from the Melanoplinae, Oedipodinae, and Acridinae (only 2 individuals) subfamilies. Gryllidae (true crickets) were also

present, with individuals from the Oecanthinae, Gryllinae, and Nemobiinae (only 3 individuals) subfamilies. We also found 2 Tettigonidae (katydids). The majority of Orthopterans collected were early instars, which made identification to lower taxonomic levels difficult.

The most abundant Dipteran families collected during vacuum and sweep-net sampling in the grasslands at JFKIA were Chloropidae (grass flies), Drosophilidae (pumpkin flies), Dolichopodidae (long-legged flies), and Syrphidae (flower flies). We were unable to identify approximately one-half (48%) of the Dipterans collected to the taxonomic level of family, due to damage to specimens presumably occurring during the collection process.

Coleoptera and Hymenoptera were present in both vacuum and sweep-net samples, although not unexpectedly the overall composition of taxa varied between the two sampling methods. Carabidae (ground beetles) and Curculionidae (snout beetles and weevils) were the most frequently observed beetles in the vacuum samples, whereas sweep-net samples were comprised primarily of Phalacridae (shining flower beetles), Coccinellidae (ladybird beetles), and Curculionidae.

Although Formicidae (ants) comprised 92% of the Hymenoptera collected by vacuum sampling, this family comprised only 23% of the Hymenoptera collected by sweep-netting. Geometridae (geometrid moths) and Noctuidae (owl moths) were the most abundant Lepidoptera, although most Lepidopteran specimens from both sweep and vacuum samples were in immature stages (only 31% were successfully identified to the family level).

The major functional feeding groups among terrestrial arthropods were represented by many arthropod families collected from the grassland habitats of the JFKIA airfield during this study. Among the 125 taxonomic families we collected, 44 were herbivores, 31 were predators, 27 were detritivores, 9 were pollinators, and 12 were parasitoid. The remaining two families (Chironomidae and Formicidae) could not be categorized into one functional feeding group.

Spatial variability of arthropod abundance and diversity

With the exception of Hymenoptera, we found no differences in the density of various arthropod taxa within the four distinct grassland habitats in vacuum samples from 2003 (Table 1). The average number of Hymenoptera captured in the Bay runway habitat area was higher ($H = 15.02$, $P = 0.002$) than Hymenoptera collected in the Between the 4s habitat area. Orthopteran (1–2) and Coleopteran family richness (6–11) was similar among habitat areas, whereas Hemiptera family diversity was highest within the Between the 4s habitat area and lowest in the Bay runway area (Fig. 2).

Table 1 Average (\pm SE) no. of arthropods per vacuum sample (0.34 m²) of selected taxonomic orders and Hemiptera suborders in four habitat areas of the airfield at John F. Kennedy International Airport, Jamaica, NY, May 2003 through September 2003

Order	No. of arthropods per vacuum sample (\pm SE)			
	Bay runway	K-extension	Between the 4s	Old meadow
Coleoptera	0.6 \pm 0.08a	0.6 \pm 0.08a	0.4 \pm 0.08a	0.6 \pm 0.14a
Diptera	0.3 \pm 0.06a	0.3 \pm 0.06a	0.2 \pm 0.09a	0.2 \pm 0.07a
Hemiptera	0.8 \pm 0.11a	1.1 \pm 0.22a	0.8 \pm 0.18a	0.1 \pm 0.17a
(Heteroptera)	0.3 \pm 0.06a	0.5 \pm 0.13a	0.3 \pm 0.11a	0.2 \pm 0.06a
(Auchenorrhyncha)	0.3 \pm 0.06a	0.5 \pm 0.14a	0.3 \pm 0.11a	0.6 \pm 0.12a
(Sternorrhyncha)	0.1 \pm 0.05a	0.1 \pm 0.04a	0.1 \pm 0.03a	0.1 \pm 0.03a
Hymenoptera	1.1 \pm 0.22a	0.8 \pm 0.16ab	0.3 \pm 0.16b	0.6 \pm 0.13ab
Lepidoptera	0.1 \pm 0.02a	0.2 \pm 0.06a	0.2 \pm 0.02a	0.2 \pm 0.04a
Orthoptera	0.1 \pm 0.02a	0.1 \pm 0.05a	0.1 \pm 0.04a	0.2 \pm 0.04a
Minor ^a	0.1 \pm 0.03a	0.1 \pm 0.02a	0.1 \pm 0.03a	0.1 \pm 0.03a
Non-insect ^b	0.3 \pm 0.07a	0.4 \pm 0.08a	0.2 \pm 0.06b	0.5 \pm 0.11a
All orders combined	3.4 \pm 0.35a	3.5 \pm 0.39a	2.3 \pm 0.35a	3.2 \pm 0.39a

Means within the same row with the same letter are not different ($P > 0.05$) according to a Kruskal–Wallis test

^a Minor insect orders included Collembola, Dermaptera, Isoptera, Mantodea, Neuroptera, Odonata, and Thysanoptera

^b Non-insect arthropods included Arachnida (Acari and Araneae), Malacostraca (Isopoda), Chilopoda, and Diplopoda

In 2003, the average number of arthropods collected in sweep-net samples in the K-extension habitat area was two to three times higher ($H = 13.57$, $P = 0.004$) than the average number of arthropods in the other three habitat areas. This difference among habitat areas was due to higher abundances of Hemiptera (specifically Auchenorrhyncha), Orthoptera (Acrididae), Diptera, and Hymenoptera in the K-extension habitat area relative to the other grasslands (Table 2). Although the Old meadow habitat area had the highest relative abundance of non-insect arthropods collected by sweep-netting, this area also had the lowest abundance of Hemiptera (especially Auchenorrhyncha) and Orthoptera (Table 2). Similar to the vacuum samples, Orthopteran (1–3) and Coleopteran family richness (6–11) was not different among habitat areas, whereas family richness of Hemiptera was highest within the Between the 4s habitat area (Fig. 2).

In contrast to the previous year (2003), the average number of arthropods collected by sweep-net during 2004 in the K-extension habitat area was lower ($H = 18.31$, $P < 0.001$) than the average number of arthropods collected in the Bay runway and Between the 4s habitat areas. The relative abundance of arthropod taxa were similar among the grassland habitat areas sampled, with two notable exceptions (Table 3). Orthoptera (mostly Acrididae: Melanoplinae: *Melanoplus*) were four times more abundant ($H = 70.69$, $P < 0.001$) in the Between the 4s habitat area than in the Bay runway and K-extension habitat areas. Hemiptera, including Heteroptera and Auchenorrhyncha, were more abundant ($H = 18.44$, $P < 0.0001$) in the Bay runway habitat area than in the K-extension and Between

the 4s grassland habitats (Table 3). Family richness of Orthoptera (2–3) and Coleopteran family richness (6–11) did not vary among the habitat areas. The Bay runway habitat area had much lower Hemipteran family richness than the other 2 habitat areas (Fig. 2).

Temporal patterns of arthropod abundance

Arthropod abundance, as assessed by vacuum sampling, did not vary among the summer months (Fig. 3). The average density of arthropods per 0.34 m² was similar during May to September in the Bay runway ($H = 7.01$, $P = 0.14$), K-extension ($H = 3.55$, $P = 0.47$), Between the 4s ($H = 0.77$, $P = 0.86$), and Old meadow ($H = 7.20$, $P = 0.13$) habitat areas.

Sweep-net sampling in 2003 showed that the relative abundance of arthropods increased during mid to late summer in all four habitat areas (Fig. 4). The average number of arthropods collected per sample in September was higher than the average number collected per sample in July in the Bay runway ($H = 16.65$, $P < 0.001$), K-extension ($H = 15.03$, $P < 0.001$), Between the 4s ($H = 15.30$, $P < 0.001$), and Old meadow ($H = 11.05$, $P = 0.004$) habitat areas. The abundance of arthropods increased three fold from August to September of 2003 in the K-extension grassland area (Fig. 3); this increase was almost entirely due to an increase in Auchenorrhyncha populations.

In contrast to 2003, patterns of arthropod abundance varied among the grassland habitat areas during summer months in 2004 (Fig. 5). The average number of arthropods

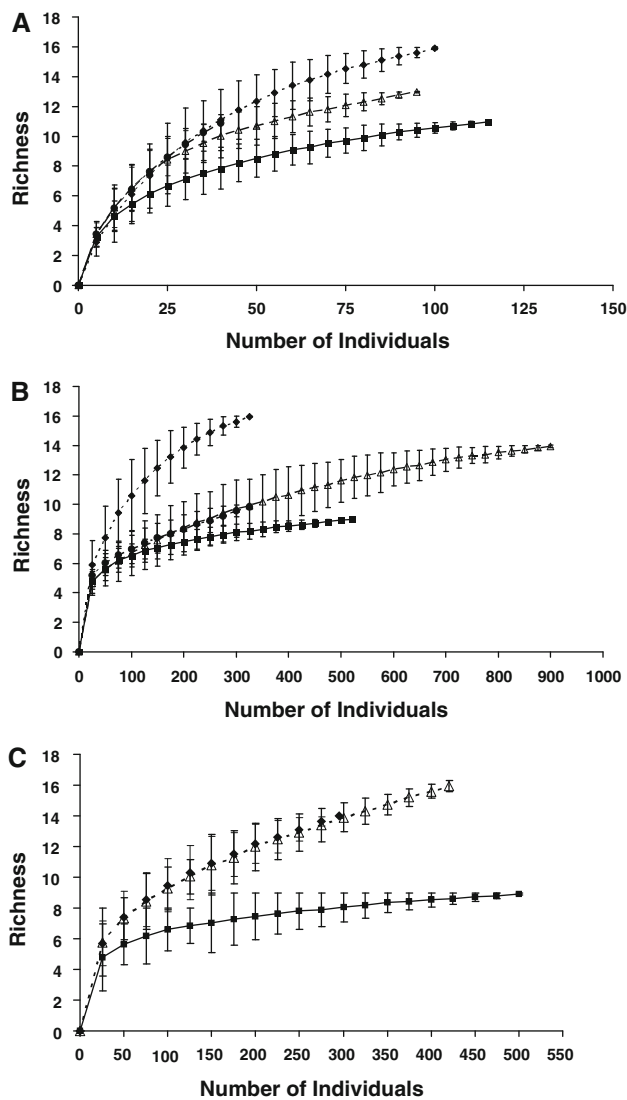


Fig. 2 Rarefaction curves for Hemiptera families collected in four grassland habitats on the airfield of the John F. Kennedy International Airport. The expected number of families is plotted against subsamples (number of individuals) and error bars are $\pm 95\%$ Confidence Intervals. The Bay runway area is represented by (solid) squares, the K-Extension area by (open) triangles, the Between the 4s area by (solid) diamonds, and the Old meadow area by (solid) circles. **a** Vacuum samples in 2003, **b** Sweep-nets in 2003, and **c** sweep-net samples in 2004

per sweep-net sample did not vary ($H = 2.58$, $P = 0.63$) among months in the Bay runway habitat area, remained constant except for a significant increase from June to July ($H = 10.79$, $P = 0.03$) in the K-extension habitat area, and decreased ($H = 15.30$, $P = 0.006$) from May to September in the Between the 4s habitat area. Variation in arthropod populations in the Bay runway habitat area in 2004 was due primarily to changes in Auchenorrhyncha abundance. Declines in Orthoptera: Acrididae abundance, the most abundant taxa in the Between the 4s habitat area in 2004,

were reflected in the overall decline in arthropods from May to September.

Discussion

Arthropod communities

The dominance of Hemiptera, Orthoptera, and Diptera in the arthropod samples collected from the grassland habitats on the JFKIA airfield is consistent with other studies examining terrestrial arthropod communities in native and agricultural grasslands (Tscharntke and Greiler 1995; Jonas et al. 2002; McIntyre and Thompson 2003). Most of the insect families collected in these semi-natural grassland habitats are closely associated with grasses and decaying vegetation. The Hemipteran families collected in the grassland habitats of the JFKIA airfield are primarily phytophagous and the most abundant Hemipteran families, Cicadellidae and Delphacidae, are closely associated with grasses and sedges (Morris 2000; Nickel and Hildebrandt 2003). The Dipteran families inhabiting the grassland habitats at JFKIA are representative of flies normally associated with grassland areas (Chloropidae), along margins of water in soil and vegetation (Dolichopodidae), or with flowering plants (Syrphidae) (Borror and White 1970; McAlpine et al. 1981; McAlpine et al. 1987). Drosophilidae (pomace flies) are generally found near decaying fruits or vegetation (Triplehorn and Johnson 2005) and this family contains numerous species affiliated with urban areas (Frankie and Ehler 1978).

Terrestrial arthropods representing all of the major functional feeding groups (including herbivores, predators, detritivores, pollinators, and parasitoids) were found in the grassland habitats of the JFKIA airfield. The most abundant Coleoptera families collected in this study reflect this and were distributed among the arthropod functional feeding groups. Curculionidae are primarily herbivorous (Triplehorn and Johnson 2005), whereas Carabidae (ground beetles) are very active, predaceous beetles (Dillon and Dillon 1972; Törmälä 1982). Coccinellidae feed primarily on aphids (Borror and White 1970). Phalacridae are pollen feeders commonly found on the flowers of *Solidago* spp. L. (goldenrod) and other composites (Asteraceae) (Triplehorn and Johnson 2005).

Spatial variability of arthropod abundance and diversity

The four grassland habitat types examined in this study represent the major components of the urban semi-natural grassland ecosystem that comprises the JFKIA airfield. These grassland habitats are relatively similar, although they have some differences in plant community composition

Table 2 Average (\pm SE) no. of arthropods per sweep-net sample of selected taxonomic orders and Hemiptera suborders in four habitat areas of the airfield at John F. Kennedy International Airport, Jamaica, NY, June 2003 through September 2003

Order	No. of arthropods per sweep-net sample (\pm SE)			
	Bay runway	K-extension	Between the 4s	Old meadow
Coleoptera	0.5 \pm 0.12a	0.9 \pm 0.22a	0.2 \pm 0.08a	1.0 \pm 0.28a
Diptera	2.4 \pm 0.35a	4.9 \pm 0.71b	3.6 \pm 0.09ab	2.0 \pm 0.32a
Hemiptera	8.5 \pm 0.95a	19.7 \pm 5.94a	9.6 \pm 1.63a	6.0 \pm 1.03b
(Heteroptera)	3.0 \pm 0.46a	6.1 \pm 3.86a	2.3 \pm 0.59a	1.9 \pm 0.46a
(Auchenorrhyncha)	5.2 \pm 0.77a	13.3 \pm 4.61a	7.4 \pm 1.40a	3.9 \pm 0.88b
(Sternorrhyncha)	0.2 \pm 0.06a	0.2 \pm 0.11a	0.0 \pm 0.00a	0.1 \pm 0.07a
Hymenoptera	0.5 \pm 0.09a	0.7 \pm 0.15b	0.3 \pm 0.16a	0.4 \pm 0.14a
Lepidoptera	0.5 \pm 0.10a	0.6 \pm 0.16a	0.6 \pm 0.02a	0.7 \pm 0.23a
Orthoptera	0.6 \pm 0.09ab	3.5 \pm 0.73c	1.5 \pm 0.04bc	0.4 \pm 0.14a
Minor ^a	0.1 \pm 0.04a	0.1 \pm 0.05a	0.0 \pm 0.00a	0.1 \pm 0.03a
Non-insect ^b	0.1 \pm 0.04a	0.3 \pm 0.10ab	0.1 \pm 0.04a	0.5 \pm 0.16b
All orders combined	13.2 \pm 1.33a	30.7 \pm 6.38b	15.9 \pm 2.35ab	11.0 \pm 1.47a

Means within the same row with the same letter are not different ($P > 0.05$) according to a Kruskal–Wallis test

^a Minor insect orders included Mantodea, Neuroptera, Psocoptera, and Thysanoptera

^b Non-insect arthropod orders included Acari and Araneae

Table 3 Average (\pm SE) no. of arthropods per sweep-net sample of selected taxonomic orders and Hemiptera suborders in three habitat areas of the airfield at John F. Kennedy International Airport, Jamaica, NY, May 2004 through September 2004

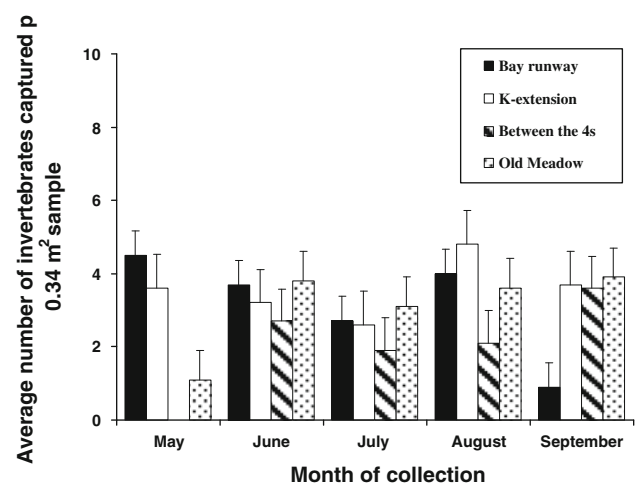
Order	No. of arthropods per sweep-net sample (\pm SE)		
	Bay runway	K-extension	Between the 4s
Coleoptera	0.4 \pm 0.14a	0.4 \pm 0.11a	0.4 \pm 0.09a
Diptera	1.5 \pm 0.26a	1.1 \pm 0.18a	1.5 \pm 0.18a
Hemiptera	10.0 \pm 2.52a	3.9 \pm 0.60b	3.4 \pm 0.52b
(Heteroptera)	2.2 \pm 0.94a	1.4 \pm 0.24ab	0.6 \pm 0.08b
(Auchenorrhyncha)	5.6 \pm 0.95a	2.0 \pm 0.25b	2.0 \pm 0.20b
(Sternorrhyncha)	2.2 \pm 0.95a	0.5 \pm 0.19a	0.7 \pm 0.45a
Hymenoptera	0.8 \pm 0.19a	0.4 \pm 0.10a	0.5 \pm 0.09a
Lepidoptera	0.3 \pm 0.08a	0.6 \pm 0.17a	0.6 \pm 0.08a
Orthoptera	1.2 \pm 0.33a	1.8 \pm 0.84a	7.5 \pm 0.84b
Minor ^a	0.1 \pm 0.04a	0.1 \pm 0.05a	0.1 \pm 0.05a
Non-insect ^b	0.2 \pm 0.07a	0.1 \pm 0.08a	0.4 \pm 0.07a
All orders combined	14.5 \pm 2.87a	8.7 \pm 1.31b	14.2 \pm 1.15a

Means within the same row with the same letter are not different ($P > 0.05$) according to a Kruskal–Wallis test

^a Minor insect orders included Neuroptera, Odonata, Psocoptera, and Thysanoptera

^b Non-insect arthropod orders included Acari and Araneae

and vegetation structure. Such variation in botanical and structural diversity results in a patchy mosaic of microhabitats within grassland ecosystems, increasing the diversity and abundance of arthropod communities (Tscharntke and Greiler 1995; Dennis et al. 1998; Morris 2000; Jonas et al. 2002). Larger grassland areas, such as the JFKIA

**Fig. 3** Average number of arthropods per vacuum sample (0.34 m²) in four habitat areas of the airfield at John F. Kennedy International Airport, Jamaica, NY, May 2003 through September 2003. Error bars represent 1 standard error. Note: The Between the 4s habitat area was not sampled in May of 2003

airfield, have the potential for more microhabitats than smaller habitat fragments (Bomar 2001).

Studies of arthropod communities in grasslands and agricultural systems suggest higher plant species richness and vegetation structural diversity (both vertical and horizontal) are correlated with increased insect diversity and abundance (Dennis et al. 1998; Wettstein and Schmid 1999; Jonas et al. 2002; Nemeček and Bragg 2008). In this study, variation in plant communities and structure among the habitat areas on the JFKIA airfield influenced the

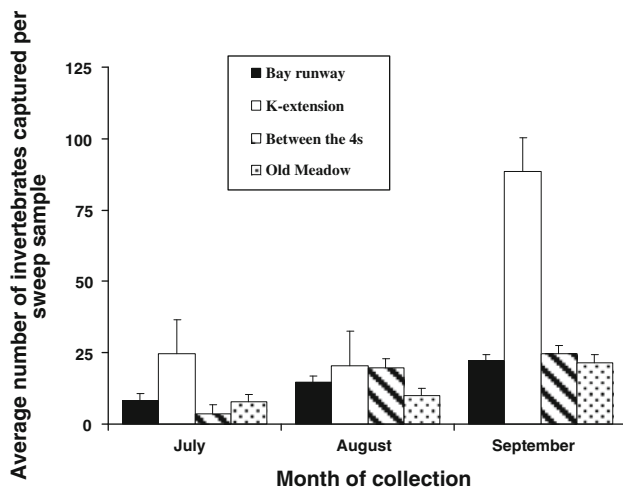


Fig. 4 Average number of arthropods per sweep-net sample in four habitat areas of the airfield at John F. Kennedy International Airport, Jamaica, NY, July 2003 through September 2003. Error bars represent 1 standard error

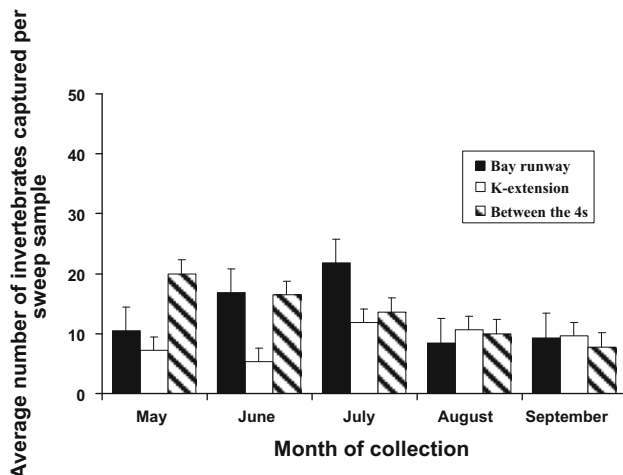


Fig. 5 Average number of arthropods per sweep-net sample in three habitat areas of the airfield at John F. Kennedy International Airport, Jamaica, NY, May 2004 through September 2004. Error bars represent 1 standard error

arthropod communities present in those habitat types. The higher abundance of forbs within the plant communities of the K-extension habitat area relative to the other habitat types could have provided a more diverse habitat structure (Söderström et al. 2001; Fuhlendorf et al. 2002; Nemec and Bragg 2008), resulting in the relatively high abundance of arthropods found in the 2003 sweep-net samples and high Hemipteran family diversity found in 2004.

The dominance of an exotic grass (*B. japonica*) within the Bay runway habitat area also provided vegetation with a high amount of vertical structure, a plant community characteristic associated with increased diversity and abundance of Auchenorrhyncha (Hollier et al. 1995; Dennis

et al. 1998; Nickel and Hildebrandt 2003). Although there was a high abundance of Hemiptera in the Bay runway area, this area consistently had lower family richness of Hemipterans compared to other habitat areas.

As evidenced by high abundance of Orthoptera: Acrididae in 2004, the Between the 4s habitat area was most similar to a managed perennial turfgrass system and apparently provided microhabitats favorable to these insects (O'Neill et al. 2003; Marini et al. 2008). Similarly, the plant community and structure of this habitat area likely provided a variety of microhabitats utilized by Hemipterans, as this habitat area consistently had the highest levels of Hemipteran diversity.

Among the grassland habitat types on the airfield, the Old meadow habitat area was the most different, due to a higher amount of woody plant cover, relatively higher amounts of native plant species (e.g., native warm-season grasses), and overall less dense vegetation at the ground level. Such differences in vegetation structure and plant community composition likely influenced the composition of arthropod communities relative to the other habitat areas (Tscharntke and Greiler 1995; Wettstein and Schmid 1999; Jonas et al. 2002).

Methods of grassland management (e.g., mowing, livestock grazing) can have deleterious effects on invertebrate diversity and abundance, although the responses might not be the same for all arthropod groups (Tscharntke and Greiler 1995; Dennis et al. 1998; Morris 2000). Hemiptera communities, most notably Auchenorrhyncha, are more diverse and abundant in taller grassland habitats (i.e., those not mowed) compared to shorter swards (Hollier et al. 2005; Morris 2000; Nickel and Hildebrandt 2003). Jonas et al. (2002) found Orthopterans were sensitive to mechanical disturbance (i.e., haying) and were more abundant in non-disturbed grasslands. Marini et al. (2008) found intensive management of grasslands (e.g., more fertilizer applications and mowing several times per year) lowered Orthopteran diversity compared to grasslands managed with less intensity. Overall, Coleoptera appear to be less affected by mowing of grasslands than other arthropod orders (Dennis et al. 1998; Morris 2000); however, phytophagous beetle abundance or diversity might be reduced due to grassland management activities (i.e., mowing) that occur on airfields (Tscharntke and Greiler 1995).

Temporal patterns of arthropod abundance

Arthropod populations, especially Hemiptera and Orthoptera, are very dynamic and can exhibit considerable variation in diversity and abundance within and among years (Tscharntke and Greiler 1995; Hollier et al. 2005; Triplehorn and Johnson 2005; Nemec and Bragg 2008). Much of

the temporal variation in arthropod abundance in the grassland habitats of the JFKIA airfield was related to changes in Auchenorrhyncha or Orthoptera: Acrididae populations. Auchenorrhyncha respond to changes in plant community characteristics, such as the reduction of vegetation height due to mowing activities (Morris 2000; Nickel and Hildebrandt 2003). Orthoptera species are particularly sensitive to climatic conditions (e.g., summer weather patterns) and microclimatic conditions related to plant community structure (O'Neill et al. 2003; Triplehorn and Johnson 2005; Marini et al. 2008).

Differences between sampling methods

A combination of arthropod sampling methods is required to effectively determine the structure and composition of terrestrial arthropod communities in grasslands due to varying effectiveness and biases associated with each sampling technique (MacLeod et al. 1994; Buffington and Redak 1998; Standen 2000). For this study, we used two standard sampling methods to characterize terrestrial arthropods within grasslands on the JFKIA airfield. Vacuum sampling captures both epiphytic (living on vegetation) and some epigeal arthropods, whereas the sweep-net sampling method primarily collects epiphytic arthropods from the upper portions of the vegetation swards (Hossain et al. 1999; Standen 2000; Morris 2000; Nickel and Hildebrandt 2003).

The vacuum (or suction) sampling method has been used successfully to sample arthropod communities in grasslands (Törmälä 1982; Brook et al. 2008) and agricultural situations (MacLeod et al. 1994; Mommertz et al. 1996; Hossain et al. 1999). However, our findings suggest that using this technique in maritime grasslands characterized by sandy soils might be problematic. During vacuum sample collection, significant amounts of sand passed through the mesh and were collected as part of the arthropod sample. The movement of this material apparently caused substantial physical damage to some collected arthropods, and consequently their poor condition made identification difficult. Although some insect taxa (e.g., Coleoptera and Hymenoptera: Formicidae) are highly chitinous and might resist being fragmented in the vacuum sampling process, enough damage occurred to prevent family level identification of approximately 25% of the Coleoptera collected in the vacuum samples (compared to 10% of Coleoptera unidentified to family level in the sweep-net samples).

Conservation value of airfield grasslands

Our results suggest the JFKIA airfield represents a large, semi-natural grassland area that has the ability to support

diverse and dynamic populations of terrestrial arthropods, although the airfield is isolated from other semi-natural grassland habitats by marine and urban environments. Given the airfield's proximity to Jamaica Bay (a marine ecosystem), the maritime semi-natural grassland plant communities of the airfield are likely influenced by salinity and other abiotic factors associated with coastlines (Morris 2000). The terrestrial environments surrounding the JFKIA are heavily urbanized areas consisting of large areas of impervious surfaces (e.g., pavement), thus the airfield likely serves as an isolated grassland habitat island with little potential for immigration or emigration of arthropods, in particular for species with limited mobility (Faeth and Kane 1978; Eversham et al. 1996; Tscharrntke et al. 2002; Öckinger and Smith 2007).

With the potential exception of Floyd Bennett Field, located near JFKIA within the Gateway National Recreation Area, the JFKIA airfield is unique when compared to other urban grasslands within the metropolitan New York City area and western Long Island (Lent et al. 1997; Greller et al. 2000). All other grasslands habitats within this highly urbanized landscape are cool-season turfgrass areas found in residential and corporate lawns, urban parks, and golf courses. These areas are highly influenced by intensive management of vegetation and insect communities (e.g., intensive mowing, pesticides). Although community-level assessments and studies of arthropods within cool-season turfgrass areas (e.g., lawns, golf courses) within the northeastern United States are almost non-existent (e.g., Rochefort et al. 2006), a review of available scientific studies about these turfgrass areas suggest lawns (Cockfield and Potter 1984; Potter and Braman 1991; Braman and Pendley 1993; Joseph and Braman 2009), golf courses (Braman et al. 2002; Yasuda and Koike 2006; Yasuda et al. 2008), and other turfgrass areas are dominated by insect pest species commonly identified as a problem within turfgrass areas (Cheng et al. 2008; Alumai et al. 2009). Future research is needed to determine the composition and diversity of arthropod communities within these urban grassland habitats in the northeastern United States and elsewhere.

Airports and military airfields represent a unique land use within urban and suburban landscapes. Airfield grasslands are managed (e.g., mowing, plant community renovation) for several reasons related to safe aircraft operations. In addition, airfield grasslands are often managed to reduce the numbers of insects (typically pest species in high abundance) that could attract birds and therefore increase the risk of bird-aircraft collisions (Caccamise et al. 1996; Bernhardt et al. 2010). Additionally, control programs might be implemented on airfields to prevent the spread of invasive insect species (e.g., *Popillia japonica* [Japanese beetles]; Hamilton et al. 2007).

However, within the management paradigm for airfield grasslands there are clearly potential benefits for conservation of arthropods in suburban and urban areas. We suggest airports can provide important grassland habitats within highly urbanized landscapes for terrestrial arthropods, similar to other unique habitats (e.g., brownfield sites, green roofs).

The semi-natural and anthropogenically produced grassland habitats on the JFKIA airfield appear to have significant conservation value for arthropod communities within this urban environment. The mosaic of grassland habitats on the airfield provides a heterogeneous semi-natural grassland environment, likely increasing biodiversity locally and within a larger urban ecosystem (i.e., the New York City metropolitan area) and potentially serves as a refugium for some terrestrial arthropod species (Faeth and Kane 1978; Panzer et al. 1995; McIntyre et al. 2001). Based on the findings from our community-level assessment, we suggest future research is needed to evaluate the value of these unique grassland habitat fragments, in particular for insect families and/or species groups of conservation interest (e.g., rare, threatened, or endangered species).

Conclusions

In summary, our study shows that arthropod populations in semi-natural grassland habitat fragments, such as those found on the JFKIA airfield, are abundant, diverse, and contain representatives from the major functional feeding groups. We found evidence of spatial and temporal variation of arthropod communities within these semi-natural urban grasslands, likely related to differences in plant community composition and vegetation structure among the habitat areas. These anthropogenically influenced grassland habitats are unique within this highly urbanized landscape which might serve as a refugium for grassland insects that require these habitats to persist. Consequently, such areas might have significant value for the conservation of terrestrial arthropods within urban areas. Future research is needed to further understand the role of semi-natural grassland habitat fragments within highly urbanized environments have in preserving and enhancing invertebrate biodiversity. In addition, we suggest future efforts assessing the value of these habitat fragments to terrestrial insects of significant conservation concern are warranted.

Acknowledgments This research effort was funded by the Port Authority of New York and New Jersey and United States Department Agriculture-Animal and Plant Health Inspection Service-Wildlife Services. We thank various members of the USDA-APHIS-Wildlife Services New York staff, especially D. Slater and A. Gosser, and the JFKIA Airfield Operations staff, especially S. Nowak, for

their assistance in the field. In addition, we thank J. Dierker and S. Johnston for assistance with data entry. T. DeVault, T. Seamans, and 2 anonymous reviewers kindly provided helpful comments on earlier versions of this manuscript.

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